FRUIT-FROST WORK IN THE GRAND VALLEY OF COLORADO.

By ANDREW M. HAMRICK, Meteorologist.

[Weather Bureau, Davenport, Iowa, Sept. 10, 1921.]

About 10 years ago the Grand Valley of Colorado was the center of one of the most active orchard-heating campaigns then being conducted in the fruit belts of the United States. Mr. E. S. Nichols, the meteorologist at Grand Junction, spared neither time nor labor in developing a system of forecasting, and dissemination of warnings, which was as nearly perfect as the facilities of the Bureau would permit.

Hundreds of fruit growers throughout the valley were warned of expected frosts, and thousands of dollars were spent each year in orchard heating. Freight rates, labor, and fuel were cheap at that time, and the prices received for fruit were relatively high. Consequently every effort was exerted to protect as much fruit as possible. Peach, apricot, pear, and apple orchards from Vineland and Palisade down the valley to Loma and Garmesa were heated by artificial means whenever there was indication of the temperature falling much below the freezing point.

However, as is usually the case in all matters which are more or less for the public's good, there were a few growers here and there who did not enter into the spirit of the campaign. Sometimes this was due to lack of funds to purchase the smudge pots and fuel; sometimes due to a disinclination to engage in the arduous duties connected with smudging; and, sometimes due to the grower's individual disbelief in the efficacy of "heating all-out-doors."

When harvest time arrived, it was often learned that the nonsmudger fared almost equally as well as the smudger in securing a good crop, and the cost of the smudging operations represented an additional profit to the grower who did not smudge. Of course, where orchard heating was carried on on such a large scale a few growers scattered throughout the district could refuse to smudge and yet their orchards would reap the benefits of the combined efforts of their neighbors, principally, because the difference in temperature between a heated and a nonheated orchard would soon set up a circulation of air beneficial alike to all concerned.

There was an inclination on the part of the nonsmudgers to boast of their success (another common trait of this class of slackers) in saving the labor and expense of smudging, and year after year new converts were added to the side that did not smudge.

Then came the World War, with its resultant high freight rates, high labor wages, and high cost of fuel, while the price of fruit (as it affected the producers), did not increase proportionately. Especially was this true of the more common fruits—apples and pears. As a result, all apple growers in the lower valley stacked up their smudge pots, and abandoned the practice of orchard heating. In the upper part of the valley, around Vineland and Palisade, the early apricots, peaches, and some early pears sold for so much more than apples per box that the growers were able to meet the increased cost of production and marketing, and still continue their protective measures.

As a result of this change in economic conditions, orchard heating had dwindled from a general community proposition in 1911 to a purely local problem in 1921. In the spring of the latter year it was confined to the Palisade peach and apricot district, with perhaps a half dozen growers outside of that area who tried to protect a few trees in their gardens. And, even in the Palisade district, heating was not general. Nearly three-fourths of the growers within that area did not prepare to smudge, thus leaving the heated orchards so badly scattered as to diminish greatly the effectiveness of the practice.

Nevertheless, the Weather Bureau did not curtail its service to the growers who desired frost warnings; even, in fact improved it by the development of formulæ for predicting the minimum temperatures which might be expected each morning.[1] This latter work had been prosecuted during the war by Mr. E. S. Nichols, who had carried out and elaborated upon suggestions made by Prof. J. Warren Smith concerning the relation between hygrometric data and minimum temperatures, until he had perfected a system which was simple of operation and yet highly accurate if the state of weather for the following morning were definitely foretold.

Early in the spring of 1921, the Grand Junction Weather Bureau office sent out notices to the effect that the Bureau would be glad to furnish warnings and predictions of expected minimum temperatures to all who cared to receive them. As a result 22 fruit growers who intended to smudge asked to be listed for telephonic advices, and 18 growers who do not smudge requested the service. The people on the list were to be advised only on dates when dangerous temperatures were expected to occur; on other dates the routine forecasts and warnings were issued by mail, and also disseminated through the daily newspapers. The full list was notified on eight occasions during the spring. However, many who were not on the list called for information, as is evidenced by the fact that during one afternoon preceding a cold night in April 81 incoming telephone calls were answered and 11 callers in person taken care of.

In addition to the telephone and published warnings service, a special service was inaugurated at Palisade. Arrangements were made with the Palisade Electric Light & Power Co. whereby a whistle warning was to be sounded whenever the temperature dropped to a degree low enough to make it necessary to light the smudge pots. Acting upon advices from the Weather Bureau office in Grand Junction, a volunteer watchman would make the rounds of observing several thermometers on critical nights, and he would inform the engineer at the light plant whenever conditions warranted sounding the alarm.

Method of forecasting minimum temperatures.—Mr. E. S. Nichols had charted on large sheets of cross-section paper numerous observations of past seasons for each of the nine substations in the valley. One diagram for the relation between the hygrometric data at the Weather Bureau office and the ensuing minimum temperatures at the substation and another diagram for the relation between the maximum temperatures at Grand Junction and the ensuing minimum temperatures at the substation. (See samples, fig. 1.) The data used in the hygrometric diagrams were obtained by means of the formula $y=a+bR$, which has been explained several times in the MONTHLY WEATHER REVIEW,[2] especially the issues of August, 1917, and May, 1918, and the maximum temperature diagrams were prepared from the data of actual observations at Grand Junction and the substations.

[1] MO. WEATHER REV., May, 1918, pp. 213-228.
[2] See Supplement No. 16, 1919.

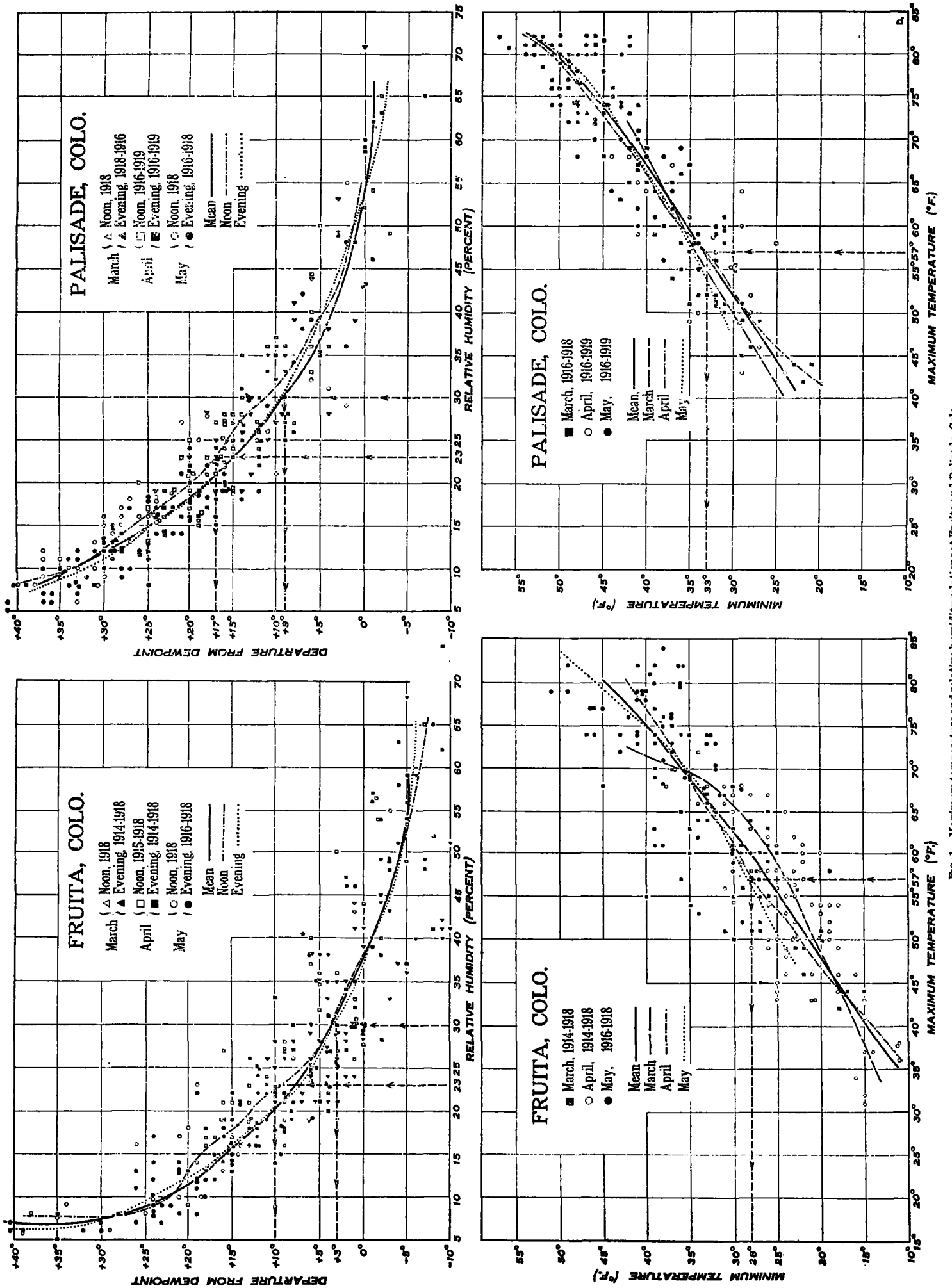

FIG. 1.—Maximum temperature and relative humidity relations at Fruita and Palisade, Colo.

Free-hand curves were drawn through the plotted observations to represent an average, rather than to use the smoother curves of the mathematical formulæ. In this way all the unexplainable variations and departures which occur in the data can readily be seen and considered, while in the curve drawn from a formula they are smoothed out. For instance, if a number of observations are "bunched" at a certain point on the diagram, probably as a result of some peculiar local condition not yet fully understood, the forecasters can incline toward this central point when his observation strikes the curve in its vicinity.

Different symbols were used for charting each month's data, and the forecaster can thus make allowances to each side of the curve to suit conditions best, and strike an even better average for a given month, or for a given decade in any particular month. Also, separate curves were drawn for the noon and evening observations; the noon data being charted in red ink and the evening data in black ink.

The preliminary advices, issued at 1:00 p. m., were based upon the regular noon observation and were, as a rule, conditional. That is, the growers were informed that the indications were for a minimum of, say, 28° at a certain station, "if the sky remained clear," etc. In making the evening predictions the forecaster had the benefit of the information which the evening weather map conveyed, and also the telegraphic advices from the district forecaster at Denver, to aid him in determining what the state of weather would be on the following morning.

The 1:00 p. m. advices were issued for the purpose of allowing the growers ample time to make all preparations during the afternoon and thus be in readiness to light their smudges should the evening predictions indicate such action necessary.

The predicted minima at 8 p. m. were usually the means of the three values secured from the hygrometric observations at noon, and at 6 o'clock, and the maximum which occurred during the afternoon. As an example, refer to the diagram for Fruita, Colo. (fig. 1, left). With a noon relative humidity observation of 23 per cent and a dew point of 17°, on a day in the latter part of April: Trace upward on the 23 line to the noon curve, as near as possible to the center of the group of *white squares,* go to the left from the noon curve and one finds the trace comes out at +10; adding 10 to the dew point, 17, gives a predicted minimum of 27° for the following morning. In like manner follow out the 6 p. m. observation: Relative humidity, 30 per cent; dew point, 25°. Going up the 30 line to the evening curve (center of black squares), and across to the left one finds +3, which added to 25 gives 28° as a probable minimum. The maximum temperature for the date in question happened to be 57° at Grand Junction. In the lower left of the same diagram the maxima at Grand Junction are charted against the following minima at Fruita. Going up the 57 line to the center of the April symbols (black squares), but inclining toward the center of the black dots because of the date being in the last decade of April, one finds that the line meets the curve at 28°. Averaging three values thus obtained gives a highly satisfactory result if clear weather prevails on the morning following the observations.

The same system, if carried out on the Palisade diagrams, gives an average of 34° for a predicted minimum at that station.

When cloudy weather is expected the forecaster must modify his predictions accordingly. In most cases, when there was a reasonable doubt about the state of weather, the forecasts were qualified by stating that "if the sky is clear at — a. m., the following minimum temperatures may be expected," and the smudgers were notified to set their alarms at the designated hour so they could arise and make an observation of the sky. If clear at the hour designated the forecasts could in variably be relied upon, and smudges were lighted; if cloudy, the smudger could again retire. That plan worked very nicely, and thus saved the growers as well as the Weather Bureau officials the inconvenience of remaining on guard throughout the night. In Palisade the volunteer watchman, previously referred to, made the observations of the state of weather at the designated hour, acting under instructions from the Weather Bureau office, and he attended to the sounding of the whistle alarm.

A form (Table 1) was printed on Map A, and each day the expected minima were computed for all stations by the different processes and entered thereon for convenience in answering telephone inquiries. The data for April 27, 1921, are given as an example. On the following morning the minimum temperatures and their departures from the predicted were entered, as were also the maxima at the substations. (It must be remembered that the substation maxima play no part in the formula, however. The cross-section paper diagrams are made from observations based on the relation between minimum temperatures at the substations and all other data at the Weather Bureau office in Grand Junction.)

TABLE 1.—*Substation reports, April 27, 1921.*

Frost?.	If clear, expect mean of (*a*, *b*, *c*) °F.	Station.	Expect— D. P. curve. Noon °F. (*a*).	D. P. curve. 6 p. m. °F. (*b*).	Max. Min. °F. (*c*).	Min. to-day. °F.	Difference. °F.	Max. yesterday. °F.
.....	29	Clifton.....	30	29	29	28	−1	56
.....	25	Fruita.....	25	24	25	25	0	60
.....	28 / 25	Fruitvale.....	25	23	26	28	(0) / 3	58
.....	25	Hunter.....	27	24	25	26	1	52
.....	25	Loma.....	27	24	25	24	−1	65
.....	26	Orchard Mesa.	28	24?	27	29	3	58
.....	[2] (27) / 31	Palisade.....	32	(27) / 31	(27) / 31	31	0	53
.....	24	Pomona.....	25	23	25	26	2	53
.....	28	Redlands.....	28	28	28	26	2	56
.....	31	Office.....	32	30	32	31	0	55

[1] Add 3° because of change in location of station since curves were prepared. New location 3° warmer than old, as a rule. Station moved in December, 1920.
[2] At old station, now closed.

Effects of low temperatures during the spring of 1921.—The fruit growers experienced a most remarkable season during the spring of 1921. At the close of January the accumulated temperature excess was 200°; at the close of February it was 289°; and at the close of March, 472°. Below normal temperatures set in about March 24, and continued throughout April, the accumulated excess since the first of the year being +342° on April 30.

The relatively warm weather during January, February, and March forced the fruit buds so rapidly that by March 18 apricots were in full bloom and peaches were beginning to show the pink. According to many growers the date of apricot blossoming equals the early record for the valley, namely, the year 1910.

Freezing temperatures occurred several times after the fruit was advanced sufficiently to be endangered, but nearly always some unexpected meteorological condition

arose to offset the usual effects of low temperatures. On at least three different occasions rains and snows preceded the cold spells in the valley, and the condensation of a bountiful supply of aqueous vapor liberated enough latent heat to protect the crop.[3] In other instances a strong "canyon breeze" sprang up at the opportune time to mix the air and prevent much further cooling after dangerously low temperatures had been reached.

As an illustration of the narrow escape from total loss observe the following table showing minimum temperatures for March and April, 1921. After the 1st of May only one station reported a minimum temperature of 32° or below, and that station (Loma) was in the extreme lower end of the valley where little fruit is now grown.

Stations.	Lowest during month.			Stations.	Lowest during month.		
	March.	April.	May.		March.	April.	May.
	°	°	°		°	°	°
Clifton	.....	23	37	Orchard Mesa	.....	23	35
Fruita	19	17	34	Palisade	24	24	39
Fruitvale	20	25	35	Pomona	17	21	35
Hunter	18	21	36	Redlands	21	21	38
Loma	17	17	32	Grand Junction	23	28	38

The Smudging Committee's Report of 1912 sets the dangerous temperature lines for peaches as follows: Buds swelling, 15°; buds in the pink, 22°; full bloom, 29°; peach setting, 31°; dropping the shuck, 31°. For apples: Bud separating, 20°; bud in the pink, 25°; full bloom, 30°; fruit forming, 30°; petals dropping, 31°.

Since temperatures several degrees below these danger lines occurred during the period of development, it is remarkable that such an excellent crop of fruit is being harvested during the present season.

Other authorities[4] give somewhat lower critical temperatures than those above quoted, but there are so many factors aside from the actual temperature which enter into the freezing of fruit on trees that each locality is a problem in itself, and these values, arrived at through local study and experiment, perhaps apply best to the Grand Valley. For example, a temperature of 29° might seriously injure peaches when in full bloom in the arid climate of the Grand Valley and at an elevation of 4,600 feet, while at the lower elevation and in the more humid atmosphere of the Pacific coast the same fruit might withstand a temperature as low as 26°.[5]

When it was learned that, in several instances, severe freezes failed to materialize on account of an abundant supply of moisture in the orchards, a few growers experimented by spraying their trees with water instead of smudging on nights when freezing temperatures were indicated. The results were unsatisfactory, however, and later most of the fruit dropped from the trees which were sprayed. It was the intention to form a coating of ice around the fruit, thus holding its temperature at 32°, but failure was due, probably, to the fact that the experiment covered a too limited area, and the cooling effect of evaporation more than offset the warmth derived through freeing of latent heat in the process of ice formation. Moreover, ice can cool to below 32°, and if the fruit were not kept incased in ice throughout the entire period of low temperatures that night it was subject to more cold than would have been experienced under natural conditions.

A survey of the valley was made after the frost season of 1921, and it was learned that 29 growers in the vicinity of Palisade (representing a total of 200 acres) lighted their smudge-pots during the spring, acting upon advices sent out by the Weather Bureau office.

In the lower valley, where orchard heating has been discontinued, there seemed to be no further need for maintaining special meteorological stations, and therefore the special stations at Loma, Hunter, Pomona, Redlands, and Orchard Mesa, Colo., were closed on June 1, 1921. It is not thought that orchard heating will ever again be popular throughout the valley.

Over 900 carloads of Elberta peaches were harvested in the Grand Valley in 1921, and over 400 carloads of pears, notwithstanding the fact that the record of minimum temperatures which occurred during the season of blossoming would, at that time, have indicated a total loss.

In this connection it may be stated that it is highly probable that irrigation is playing an important part in making conditions better for fruit raising without artificial heating in the Grand Valley. Year after year since 1911 more land has been artificially watered. The relative humidity is thus increased over a large area, and this is favorable to the formation of local fog and clouds, and also to the liberation of considerable natural heat in the processes of condensation and frost formation. A map showing the Grand Valley appeared in the MONTHLY WEATHER REVIEW, for November, 1915, page 563.

DISCUSSION.

By E. S. NICHOLS, Meteorologist.

[Weather Bureau, San Jose, Calif., Sept. 24, 1921.]

Acting on suggestion by Mr. Hamrick, I am submitting the following remarks, not to controvert, but to supplement those made by him.

Even more than Mr. Hamrick does, I should emphasize economic conditions and results of experience in explaining the decline of orchard heating in the Grand Valley.

My first spring in the valley was that of 1911, at which time our fruit-frost service had been established only in a very informal manner. Orchard heating was at its height, though not by any means universal in the district. Unusually cold weather occurred during April; orchard temperatures as low as 15° and 16° were recorded in places on the 13th; and vigorous heating was practiced night after night.[6] Much fuel and labor was expended without evident adequate profit in the way of increased returns from the fruit crop, particularly in the apple districts. Consequently many growers in those districts failed to prepare to "smudge" during the season of 1912.

I thought that a revival of orchard heating would result from improvement in the Weather Bureau's forecasting and warning system and from better methods of heating and increase of knowledge regarding its results. In later years there were temporary revivals; but a combination of conditions prevented general resumption. For not only did the valley suffer from the general depression through which the fruit industry passed during several years, but, particularly in its lower sections, it had serious problems of its own. Also, experience has shown that, often a spring freeze kills only a portion of the fruit in an orchard,[7] and a full crop may be matured from a small percentage of the blossoms.

[3] "Cold air prevents severe freeze." MO. WEATHER REV., April, 1921.
[4] *Farmers Bulletin No. 1096.*
[5] See Nichols, E. S.: Damage by frost in western Colorado, MO. WEATHER REV., April, 1913, p. 608.
[6] See MO. WEATHER REV., Apr., 1911, 39:591.
[7] See MO. WEATHER REV., *Supplement No. 16*, p. 37, and Mr. Hamrick's report for 1921.